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Some Mechanical Properties of Experimental Mg-Al-RE-Mn Magnesium Alloys

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Abstract

The results of some mechanical properties of four Mg-5Al-xRE-0.4Mn ($x = 1 - 5$) alloys are presented. The microstructure of experimental alloys consisted of an α -Mg phase and an $\alpha+\gamma$ semi-divorced eutectic, $Al_{11}RE_3$ phase and an $Al_{10}RE_2Mn_7$ intermetallic compound. For gravity casting in metal mould alloys, Brinell hardness, impact strength, tensile and compression properties at ambient temperature were determined. The performed mechanical tests allowed the author to determine the proportional influence of the mass fraction of rare earth elements in the alloys on their tensile strength, yield strength, compression strength and Brinell hardness. The impact strength of the alloys slightly decreases with a rise in the rare earth elements mass fraction.

Keywords: Magnesium alloy, Aluminum, Rare earth elements, Mechanical properties

1. Introduction

Magnesium alloys are light metallic structural materials and have a unique combination of properties which are very attractive in such applications as the automobile, aerospace and electronic industries. The use of magnesium alloys has become significant due to the one-third lower density of magnesium compared to aluminium, improved damping ability, higher resistance to corrosion and better mechanical properties.

Although, Mg-Al alloys seem to be most extensively used magnesium alloys, still the number of commercially available magnesium alloys is limited, especially for application at temperatures higher than 120°C [1,2]. The poor elevated-temperature properties of Mg-Al alloys are related to the occurrence of the intermetallic phase $Mg_{17}Al_{12}$. Recently, considerable efforts have been made to improve the creep

resistance of magnesium-aluminium based alloys via further additions of alloying elements and the formation of thermally stable phases along the grain boundaries to resist deformation by grain boundary sliding. Improvement of the elevated-temperature properties is done by the addition of elements like Sb [3,4], Bi [4], Si [3,5], Sr [6] and rare earth (RE) [7-17] for modifying the microstructure, changing the grain size and forming phases which would strengthen the grain boundaries. Rare earths are important alloying elements for magnesium alloys, which improve the purity of the alloy melt and casting characteristics as well as refine the microstructure, mechanical properties and anti-oxidization properties. Rare earth elements have been used in magnesium alloys for many years, whereas alloys from the Mg-Al-RE system have been developed recently. Commercial AE series alloys exhibit major improvement in creep resistance due to the complete suppression of $Mg_{17}Al_{12}$ intermetallic compounds and the formation of highly thermal stable Al-RE phases like

$Al_{11}RE_3$ or Al_2RE . Especially the $Al_{11}RE_3$ intermetallic compound exerts an advantageous influence on the mechanical properties of alloys.

Earlier studies allowed one to successfully introduce rare earth elements (in the form of cerium rich misch metal) into the AZ91 and AM50 magnesium alloy [15-17] and the microstructure stability of the alloys during prolonged annealing was investigated. In the present work, the mechanical properties of gravity cast Mg-Al-RE-Mn type experimental alloys are presented.

2. Experimental procedures

The experimental magnesium alloy with the chemical composition given in Table 1 was used in this study. Experimental casts were produced by the gravity casting method into a steel mould (15 x 30 x 150 mm). Microstructural analyses were performed by means of light microscopy (LM). A standard metallographic technique was used for sample preparation which includes wet pre-polishing and polishing with different diamond pastes. The specimens were examined with a Neophot-21, Carl-Zeiss Jena microscope.

Table 1.

Chemical composition of the experimental magnesium alloys

Alloy denotation	Chemical composition, wt.%			
	Al	RE*	Mn	Mg
AEM510	5	1	0.4	rest
AEM520	5	2	0.4	rest
AEM530	5	3	0.4	rest
AEM550	5	5	0.4	rest

*RE – cerium rich misch metal

The mechanical properties tests of the experimental alloys were carried out according to relevant PN standards, at room temperature, on an MTS-810 Servo-hydraulic testing machine. Signals indicating the tension force and elongation were collected directly by an X-Y computer recorder. The performed tests included experimental determination of (i) tensile strength, (ii) yield strength, (iii) compression strength and (iv) yield strength under compression (used extensometer model MTS 632.25C-23). Additionally, the Brinell hardness (steel ball: 5 mm diameter; load: 2451 N) and impact strength (IS) (Charpy V hammer; impact energy: 150 J) were determined

3. Results and discussion

Figs. 1a and b show a typical as-cast microstructure of experimental alloys AEM510 and AEM550, respectively. The visible dendritic structure is typical for cast magnesium alloys, which are characterized by very heavy segregation of the alloying elements. The microstructure consisted of primary α -Mg dendrites (impoverished in alloying elements), the partially divorced eutectic $\alpha+\gamma$ (where γ is the intermetallic compound $Mg_{17}Al_{12}$) and the $Al_{11}RE_3$ intermetallic compound. In the investigated alloys, an $Al_{10}RE_2Mn_7$ intermetallic phase is also

present due to the manganese addition to the chemical composition of the alloys. It should be noted that the volume fraction of $Al_{11}RE_3$ increases with a rise in the rare earth elements mass fraction in the chemical composition of the alloy. Simultaneously, the volume fraction of the $\alpha+\gamma$ eutectic decreases, and in the AEM550 alloy it is practically negligible.

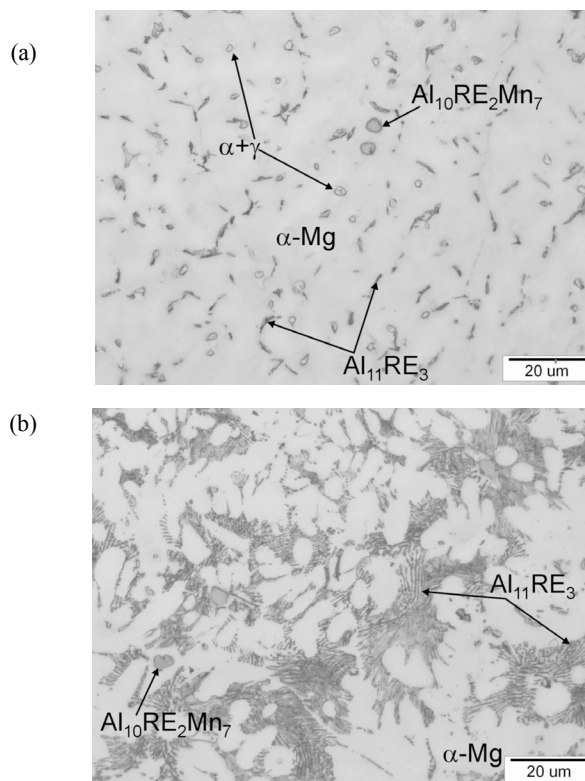


Fig. 1. Microstructure of experimental alloys: AEM510 (a), AEM550 (b)

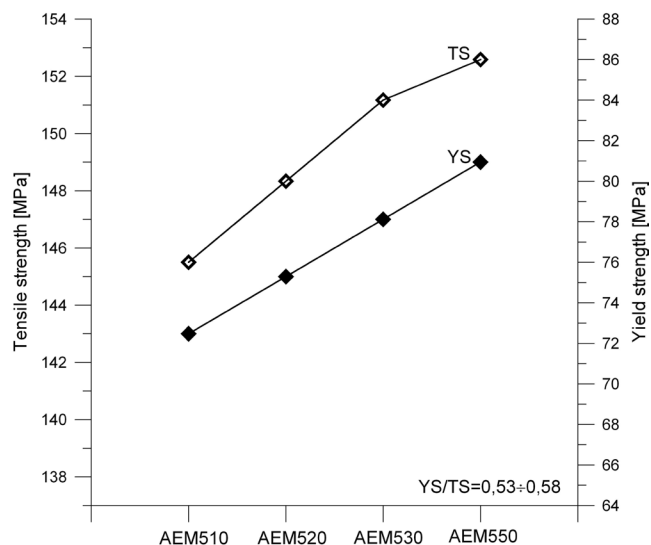


Fig. 2. Tensile strength (TS) and yield strength (YS) for experimental alloys (uniaxial tensile test)

Fig. 2 presents the tensile strength and yield strength obtained in the uniaxial tensile test versus the chemical composition of the investigated alloy (i.e. mass fraction of rare earth elements). The analogical curves presenting the values of the compression strength and yield strength obtained in the uniaxial compression test are shown in Fig. 3. Additionally, the results of the Brinell hardness and impact strength for the investigated alloys are presented in Fig. 4

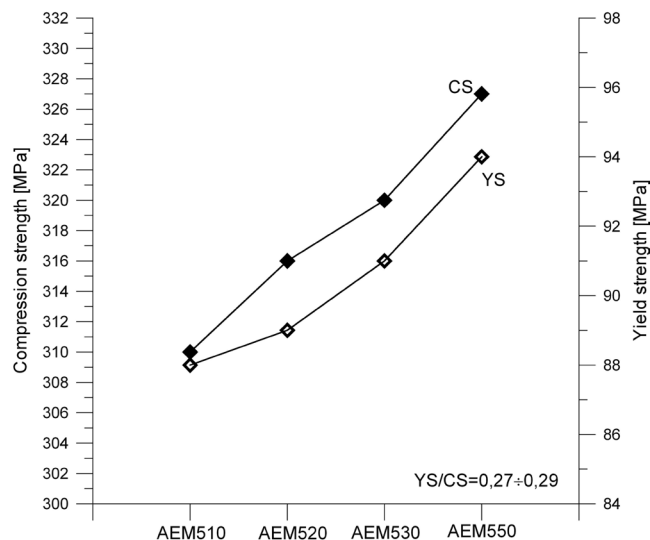


Fig. 3. Compression strength (TS) and yield strength (YS) under compression for experimental alloys (uniaxial compression test)

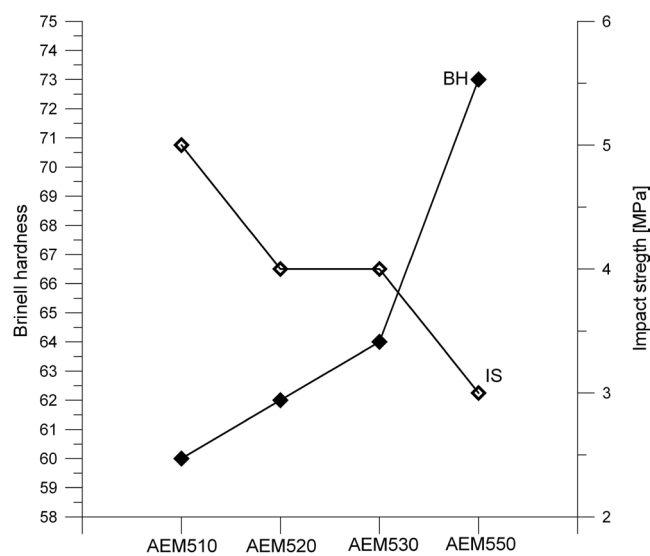


Fig. 4. Brinell hardness (BH) and impact strength (IS) for experimental alloys

As was revealed, the tensile and compressive properties increase with a rise in mass fraction of rare earth elements in the investigated alloys, though the increase is not very high. It is

connected with the amount of $Al_{11}RE_3$ phase. Although the $Al_{11}RE_3$ phase has a plate-like morphology it probably blocks the dislocation mobility. On the other hand, the increase in mass fraction of the rare earth elements in the chemical composition of the alloys and formation of the $Al_{11}RE_3$ phase caused a reduction of the primarily dendrite α phase dimension (Fig. 1), which could also influence the mechanical properties of the alloys. The volume fraction of the $Al_{11}RE_3$ phase also influences in direct proportion the Brinell hardness of the alloys. Different results were obtained in the impact strength test. The increase in mass fraction of the rare earth elements in the alloy caused slight a decrease in this property.

4. Conclusions

The effect of the mass fraction of rare earth elements on the mechanical properties of gravity cast Mg-5Al-xRE-0.4Mn ($x = 1 - 5$) experimental alloys has been studied. The obtained results show the significant influence of rare earth elements on the Brinell hardness, tensile and compression properties. An increase in the ambient temperature properties of the alloys with a rise in the mass fraction of rare earth elements results from the increase in volume fraction of the $Al_{11}RE_3$ phase and suppression of the volume fraction of the $\alpha+\gamma$ eutectic in the microstructure of the alloys.

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